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Canada/NB MDA Project on Mine-shaft Rope Testing; testing of $1\frac{3}{16}$ in., 1×136, F.L.C., H. R., (our rope #3)

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21 pp

CANADA/NB MDA PROJECT ON MINE-SHAFT ROPE TESTING; TESTING OF $1\frac{3}{16}$ in., 1×136, F.L.C., H. R. (OUR ROPE #3)

by

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ABSTRACT

In this report the authors analyse the test-results obtained non-destructively on a $1\frac{3}{16}$ in. diameter, 1×136, full-locked-coil (F.L.C.), hoist-rope (H.R.). The rope was only examined reel-to-reel as part of CANMET's project to comparatively evaluate the performance of a range of EM wire-rope testers. However, results of previous in-situ testing were also available. This is the first time that a project of this magnitude and diversity has been undertaken.

The rope was tested with the Canadian Magnograph, Rotesco AC, and Rotescograph, with the American LMA-250, and with the German WBK instruments. The maximum estimated strength-loss (LBS) was reported as being negligible by the Rotescograph operator, and at 1.5% by the Magnograph operator. The operators of the American and German instruments did not submit LBS estimates.

Within the context of CANMET's present project it was intended to only test ropes that were in a bad, or very bad, condition. In this context the condition of our rope #3 was too good. However, the results are of interest because they were obtained with a range of five instruments, and five operators. We could, therefore, record comparative results from both a hardware and operator point of view.

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Keywords: New Brunswick; Mineral Development Agreement; Wire-ropes; Non-destructive-testing; Electro-magnetic instruments; Hoist-ropes; Locked-coil ropes

PROJET EEM CANADA/NB SUR L'ESSAI DES C╢BLES DE PUITS DE MINE; ESSAI DE CL ╖ TEC, 1X136, DE 1 3/16 PO (NOTRE C╢BLE NO 3)

par

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RÉSUMÉ

Dans le présent rapport, les auteurs analysent les résultats d'essais non destructifs menés sur un câble de levage (CL) à torons entièrement clos (TEC), 1x136, de 1 3/16 po de diamètre. Le câble n'a été examiné que d'une extrémité à l'autre dans le cadre du projet de CANMET visant à évaluer comparativement les rendements de divers appareils ÉM d'essai des câbles métalliques. Cependant, les résultats d'essais antérieurs menés sur place étaient aussi disponibles. C'est la première fois qu'un projet de cette ampleur et de cette diversité est entrepris.

Le câble a été essayé avec le Magnograph, le Rotesco AC et le Rotescograph canadiens, avec l'instrument LMA-250 américain et avec les instruments WBK allemands. La perte de résistance (LBS) maximale a été estimée à 0 % par l'opérateur du Rotescograph, et à 1,5 % par l'opérateur du Magnograph. Les opérateurs des instruments américain et allemands n'ont soumis aucune estimation de LBS.

Dans le contexte du présent projet de CANMET, le but était seulement de tester des câbles qui sont dans un état mauvais à très mauvais. Dans ce contexte, l'état de notre câble no 3 était trop bon. Cependant, les résultats présentent de l'intérêt parce qu'ils ont été obtenus avec cinq instruments par cinq opérateurs. Nous pourrions donc obtenir des résultats comparables sans égard au matériel ou à l'opérateur.

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Mots clés: Nouveau-Brunswick; Entente sur l'exploitation des minéraux; câbles métalliques; essai non destructif; instruments électromagnétiques; câbles de levage; câbles à toron clos

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BACKGROUND

The results described in this report constitute an integral part of the contracted phase of CANMET's project, undertaken in 1986 in response to requests by both the mining industry and the mine regulatory authorities. The basic project objectives specified that the continuing rope failures, or near failures — occurring despite mandatory wire-rope examinations with electro-magnetic (EM) instruments at regular intervals — be examined, documented, analysed, and the reasons for these occurrences clarified. This is the first time a project of this scope and depth has been undertaken, anywhere.

CANMET's work included both in-house and contracted work phases. The in-house phase resulted in a range of conclusions and recommendations, reported elsewhere (references 1 through 6). We are now in the process of reporting the results obtained during the contracted project-phase, which included an extensive series of both in-situ and shop-floor tests. The first fourteen reports to describe this project phase were prepared in the period February, 1990, through April, 1991 (references 7 through 20). More are to follow.

ROPE DETAILS

The rope of current interest (referred to as "our rope #3") was designated #3 Head Rope in Shaft #2, compartments 4 and 5 (cage and counterweight) of International Nickel Company of Canada's (INCO) Shebandowan mine at Shebandowan, Ontario. It was manufactured by Wire Rope Industries Ltd. of Pointe Claire, Quebec. Its reel number was L-11154. It measured $1\frac{3}{16}$ in. diameter × 2,600 ft. It was of a 1×136 FLC construction (gallery 1: 1×.076; 8×.044; 8×.086; 8×.057; 8×.076; 16×.087; gallery 2: 23×.080; 14×.110; gallery 3: 14×.110/.156; gallery 4: 36×.36 in.), with a mass of 3.41 lb/ft; left regular lay; galvanized. Its breaking strength was 188,550 lb. It was installed on 1978 06 12*, and removed on 1988 09 17, i.e., it was in use for 10 years and 2 months. However, while the rope was in-situ all this time, and tested at regular four monthly intervals, the mine was shut-down from 1985 through 1988.

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*: dates are given in this order: year, month, day

IN-SITU TEST RESULTS — AS REPORTED AND REVIEWED

The Rotesco AC data

In-situ test results were obtained by INCO staff with a Rotesco AC instrument on a routine regulatory basis. The last in-situ test before rope removal was performed on 1988 05 26 (test #SH-371). A copy of the relevant strip-chart is reproduced in Fig. 1a. The operator reported a loss of breaking strength (LBS) of 7.0% between 1,050 ft and 1,350 ft from start of the test at the cage rope-end. Since, for this rope-size, the operator used a %LMA (loss-of-metallic cross-sectional area) to %LBS conversion factor of 1.5, the reported 7.0% LBS would indicate a 4.7% LMA at the given rope locations. Nowhere along the approximately 2,450 ft of tested rope-length could we, however, detect a %LMA chart-reading of 4.7%. The maximum %LMA (LMA_{max}) chart-reading was 2.5% at the counterweight (ctwt) rope-end (Fig. 1a). Moreover, the worst rope segments were at the two rope-ends, with 0.0% LMA at the very 1,050 ft to 1,350 ft rope segment where the operator reported maximum losses. Perhaps, the operator was misled by the conspicuous perturbation of the 'R' (i.e., eddy-current) chart-trace at this rope-section.

We can not explain why the eddy-current chart-trace should show a drastic decrease at the very rope section where the metallic area chart-trace shows an increase (Fig. 1a). Something was, perhaps, amiss with the instrument, or, possibly, electrical transients were a problem.

SHOP-FLOOR TEST RESULTS — AS REPORTED AND REVIEWED

General procedure

The shop-floor tests were undertaken, reel-to-reel, with a Rotesco AC, a Rotescograph, a Magnograph, and an LMA-250 instrument, as well as with the prototype version of the latest German WBK tester. None of the operators knew about each other's results before these were submitted to us. All details of the testing process were described, and illustrated, elsewhere (7).

Rather than the full 2,450 ft rope-length that was tested in-situ, only some 1,020 ft (i.e., less than half the total length) were available for shop-floor testing. Unfortunately, we were not told from which part of the in-situ rope this length was cut. Nor could we detect any characteristic rope-defects that might have answered this question unequivocally. We believe, though, that the shop-floor rope-length probably represents the first 1,020 ft of the strip-chart reproduced in Fig. 1a.

The Rotesco AC data

The Rotesco AC data were obtained on 1989 04 03, a day before the permanent magnet instruments were used. This was done to ensure proper rope demagnetization. The shop-floor strip-chart is reproduced in Fig. 1b. We assume that here too, as in the field, testing started at the cage rope-end.

The seizing wire markers, on a 250 ft spacing, show up well. In Fig. 1b they are identified by the symbol 'M'.

The operator, quite correctly, set the 0.0% LMA reference level at the 800 ft rope end of the shop-floor test run. On comparing Figures 1a and 1b it may be noted that the reference level at 800 ft from test-start is some 1.0% below the 0.0% LMA reference level of the in-situ rope. The operator reported an LMA_{max} of 1.4% at 285 ft from start of the test. This represents an LBS_{max} of $1.4\% \times 1.5 = 2.1\%$.

We agree with the operator's report, *per se*, even if the LMA_{max} chart-reading could, perhaps, be slightly greater, say 1.5% (see Fig. 1c), with a corresponding LBS_{max} of some 2.4%. We also wonder about the presence of those numerous spikes on the LMA chart-trace that do not represent rope-markers. Moreover, the eddy-current chart-trace appears to be exaggerated. Something was, perhaps, amiss with the instrument. Or did electrical transients cause the problems?

The Rotescograph data

The operator tested some 1,060 ft of rope on 1989 04 04 (Fig. 2a) and some 1,000 ft on 1989 04 10 (Fig. 2b). The first test started at the cage rope end, and the second at the counterweight rope-end. The seizing wire markers, on a 250 ft spacing, showed up well. The operator identified them by writing 'Marker' on the chart (Fig. 2a). No LMA chart-readings were recorded. We added the 100% reference level and the LMA_{max} value to Fig. 2a ourselves. No report was submitted for the 1989 04 04 test run. For the 1989 04 10 test, though, the operator reported (report #ME0005RPN) that there was "no metallic area loss, and no depreciation in the breaking strength of this rope. The results from the test of this rope appeared to be the same as results from a new rope, providing that uniform wear did not occur during service of this rope". Again, no LMA chart-readings were recorded. We, ourselves, marked the operator's chart (Fig. 2b).

We think the operator somewhat overstated the pristine condition of the rope by not reporting any losses at all.

The Magnograph data

The operator reported (report #89-286H) having tested, on 1989 04 04, a rope length of 1,021 ft (Fig. 3). The seizing wire markers, on a 250 ft spacing, showed up well. In Fig. 3 they are identified by the symbols 'Mk 0 pi'; 'Mk 250 pi'; etc. Testing started at the cage rope-end. The 0.0% LMA reference level was, correctly, placed at this rope-end. The LMA_{max} of 1.5% was reported between markers M1 and M2, some 81 to 138 ft after M1. The LBS_{max} was reported to be equal to the LMA_{max}, i.e., some 1.5%. The operator also commented that the 'true' breaking strength of this F.L.C. rope might, in fact, be greater than the original one, due to metal hardening effects.

We agree with the reported data, except that the LMA_{max} should be 2.0%, rather than 1.5% — a relatively minor adjustment in absolute terms.

The LMA-250 data

The operator reported having tested a rope length of some 1,019 ft (Fig. 4) on 1989 04 04. The seizing wire markers, on a 250 ft spacing, showed up well. They are identified by the symbols 'M1'; 'M2'; etc., in Fig. 4. Testing started at the cage rope-end. The 0.0% LMA reference level was placed correctly. An LMA_{max} of 1.6% was read off the chart between markers M1 and M2, some 106 ft along the tested rope. No LBS estimates were submitted.

We agree with the reported data.

The WBK data

Shop-floor testing was performed on 1989 04 10 with the German WBK instrument — concurrently with the second Rotescograph test-run. The rope length tested was 1,048 ft (319.5 m). The strip-chart contains, reading from top-to-bottom: five LF traces, a %LMA trace, and a length indication scale (in meters). There is also space for a second %LMA trace and for a rope-diameter indication-trace (not used in the current test-series). With the sensor-head closed, the individual measuring coils LF #1 and LF#2 were joined together, and so were #3 and #4. The fifth LF chart-trace summarizes the output of these two individual traces. Surface defects, such as the seizing-wire markers, were particularly conspicuous on this instrument's LF and LMA traces.

The two WBK operators carefully annotated their charts, including some LMA readings and the seizing-wire marker (M1 to M5) locations. They also submitted a report. Testing commenced at the ctwt rope-end. The LMA difference between the two

rope-ends was 0.0%, if we too ignore the minor LMA in the final few ft of rope, as was done by the operators of the other instruments.

We did not receive a copy of the complete strip-chart. Instead copies of the important chart sections were submitted, numbered Figures 3.1 to 3.9, inclusive. We reproduce these as our Fig. 5. As may be seen, the 0.0% LMA reference level was set along the cage-end rope section; the %LMA scale was 0.304% per mm of full-scale diagram (see 'Fig. 3.1' of our Fig. 5). We added our own marking of the height of the %LMA chart-spikes at the seizing-wire markers M2 and M5. Test results are tabulated in Table 1.

The German report included a tabulation of the M1 to M5 marker locations. It is interesting to note that the tabulated distance between these markers was consistently 76 m (249.3 ft). The corresponding 'true' distance was 250 ft.

We agree with the operators' report.

DESTRUCTIVE TESTING

The in-situ and reel-to-reel shop-floor tests of rope #3 did not indicate any deterioration of sufficient severity to warrant destructive testing of any of the rope segments.

ANALYSIS OF TEST RESULTS

(1) General comments

Considering the influence of the instrument calibration-procedures upon the test-results, we included relevant information about these matters in Table 1, such as: (a) the rope-end at which calibration was effected, (b) the rope-segment at which 0.0%LMA was found to be, and (c) the %LMA difference between the two rope-ends.

Wherever we were unable to reproduce the strip-charts in a single length, we provided match-marks (such as: ref. 'A'; ref. 'B'; etc.) on the individual chart-segments. Moreover, we added to all charts: (a) the 100% reference levels, (b) the relevant sensitivity scales (%LMA per major chart-division), and (c) the %LMA chart-readings at the most important rope-locations. It should be noted that our rope #3 represented less than half of the original, in-situ, rope-length. Moreover, its 0.0% LMA level was, in all likelihood, some 1.0% below the 0.0% LMA reference level of the in-situ rope.

The rope was in a relatively good condition. The major interest in examining it was the opportunity to compare test-results obtained with five different instruments, and operators.

Details of the test set-ups are listed in Table 2.

(2) LF chart-readings

Broken wires were not of major significance. Nor was there evidence of any corrosion of consequence.

(3) LMA chart readings

We tabulated the %LMA chart-readings in Table 1. We agree with the reported values for the shop-floor test series. However, we think that the operator misread the in-situ strip-chart.

Comparative evaluation of the five EM instruments used can, perhaps, be best based on the LMA chart-readings (Table 1) obtained at the five seizing-wire rope-marker locations M1 to M5. These markers consisted of $\frac{1}{16}$ in. diameter wire, wound around the $1\frac{3}{16}$ in. rope at 250 ft intervals along 2 in. stretches. Noting that the metallic cross-sectional area (A) of the rope itself was assumed to be 0.9154 in^2, addition of the seizing-wire represented a metallic area increase of some 24%. It will be noted that in Table 1 we listed both the %LMA chart-readings, and the height of the LF trace perturbations (i.e., 'spikes'), at these markers. The 'spikes' on the WBK chart-traces are particularly conspicuous.

In this context, though, we must also emphasize the different quantitative resolution of the five instruments. As an example, for the Magnograph we noted (see Fig. 32c in ref. 7) that a 2.0 in. long rope-anomaly will only produce some 36% of the numerically correct reading on the instrument's LMA strip-chart. In the present case, therefore, only some 36% of 24%, or about 8.6%.

The rope was in a relatively good condition, with the LMA_{max} not exceeding 1.6%.

(4) LBS estimates

Since we did not perform any destructive rope testing, we had no way of checking the accuracy of the operators' LBS estimates. These were, in any case, too small to be of any practical interest.

(5) Repeatability and comparability

It is remarkable how consistently the different instruments, and operators, produced the same qualitative results. There were few, if any, characteristic rope anomalies. Quantitative comparisons were of little interest, due to: (a) the uncertainty about the true location of the 100% reference level, since the total original rope-length was not available, and (b) the relatively good condition of the rope.

We could not make any meaningful comparisons between the in-situ and shop-floor test results, because the full in-situ rope-length was not available to us on the shop-floor. In such a case only total-metallic-area (TMA) measurements, as described elsewhere (17), can provide legitimate comparisons.

REFERENCES

1. Geller, L.B.; and Udd, J.E. "How accurate are non-destructive-testing based estimates of mine shaft rope breaking-strength losses? — an update"; CIM Bull., 83, no. 944, pp. 47-50; December, 1990.

2. Geller, L.B.; Udd, J.E.; and Mitchell, E.W. "Comparative evaluation of mine-shaft wire-rope NDT instruments: a search for, and analysis of, background information — contribution to the Canada/USBM/Ontario MOL joint R&D program"; CANMET Division Report MRL 88-78, 139 pp; July, 1988.

3. Geller, L.B.; Anderson, G.L.; Miscoe, A.J.; and Mitchell, E.W. "The safety of mine-shaft wire-ropes — cooperative work by Canada and the U.S.A."; CANMET Division Report MRL 89-14, 28 pp; February, 1989.

4. Geller, L.B.; Udd, J.E.; Blanchard, R.; and Daniel, K.E. "About electro-magnetic wire-rope testing in New Brunswick mines, and related data"; CANMET Division Report MRL 89-40, 51 pp; October, 1989.

5. Geller, L.B.; and Rousseau, G. "Effect of trapped wire-rope debris upon an EM instrument's LMA chart-trace"; CANMET Division Report MRL 90-08, 29 pp; February, 1990.

6. Rousseau, G.; and Geller, L.B. "Étude des performances de deux instruments électromagnetiques pour détecter les défaults localisés (LF) dans les câbles d'acier"; CANMET Division Report MTL 90-46, 49 pp; September, 1990 (in French).

7. Geller, L.B.; Rousseau, G.; and Poffenroth, D. "Canada/NB MDA project on mine-shaft rope testing; stranded ropes with artificial defects"; CANMET Division Report MRL 90-015, 117 pp; February, 1990.

8. Geller, L.B.; Poffenroth, D.; Udd, J.E.; and Hutchinson, D. "Canada/NB MDA project on mine-shaft rope testing; testing of 1 1/4 in., FLC, H.R. (our rope #4)"; CANMET Division Report MRL 90-044, 76 pp; May, 1990.

9. Geller, L.B.; Poffenroth, D.; Udd, J.E.; and Hutchinson, D. "Evaluation of EM rope testers: Canada/US joint work"; CANMET Division Report MRL 90-052, 24 pp; June, 1990.

10. Geller, L.B.; Poffenroth, D.; Udd, J.E.; and Hutchinson, D. "Canada/NB MDA project on mine-shaft rope testing; testing of 1 7/16 in., FLC, H.R. (our rope #5)"; CANMET Division Report MRL 90-053, 46 pp; June, 1990.

11. Geller, L.B.; Poffenroth, D.; Udd, J.E.; and Hutchinson, D. "Canada/NB MDA project on mine-shaft rope testing; testing of 1 7/8 in., 34×7, NR, T.R., (our rope #9)"; CANMET Division Report MRL 90-060, 48 pp; July, 1990.

12. Geller, L.B.; Poffenroth, D.; Udd, J.E.; and Hutchinson, D. "Canada/NB MDA project on mine-shaft rope testing; testing of 1 7/8 in., 34×7, NR, T.R., (our rope #12)"; CANMET Division Report MRL 90-069, 30 pp; July, 1990.

13. Geller, L.B.; Poffenroth, D.; Udd, J.E.; and Hutchinson, D. "Canada/NB MDA project on mine-shaft rope testing; testing of 1 1/2 in., 60×30, H.R. (our rope #7)"; CANMET Division Report MRL 90-071, 128 pp; August, 1990.

14. Geller, L.B.; Poffenroth, D.; Udd, J.E.; and Hutchinson, D. "Canada/NB MDA project on mine-shaft rope testing; testing of 1.000 in., H.R., (our rope #1)"; CANMET Division Report MRL 90-131, 43 pp; December, 1990.

15. Geller, L.B.; Poffenroth, D.; Udd, J.E.; and Hutchinson, D. "Canada/NB MDA project on mine-shaft rope testing; testing of 1.000 in., 6×27, FS, H.R., (our rope #2)"; CANMET Division Report MRL 91-001, 30 pp; January, 1991.

16. Geller, L.B.; Poffenroth, D.; Udd, J.E.; and Hutchinson, D. "Canada/NB MDA project on mine-shaft rope testing; testing of 1 3/4 in., 6×25, RS, H.R., (our rope #10)"; CANMET Division Report MRL 91-002, 30 pp; January, 1991.

17. Geller, L.B.; and Kitzinger, F. "Techniques to better exploit the possibilities of wire-rope testing with electro-magnetic instruments"; CANMET Division Report MRL 91-003, 70 pp; January, 1991.

18. Rousseau, G.; and Geller, L.B. "Analysis of the NDT reports relating to the June 23, 1990, hoist-rope failure in Elliot Lake, Ontario"; CANMET Division Report MTL 90-67, 79 pp; November, 1990.

19. Geller, L.B.; and Udd, J.E. "NDT of wire ropes with EM instruments — an examination of operational conditions in Canada"; CANMET Division Report MRL 91-019, 23 pp; March, 1991.

20. Geller, L.B.; Poffenroth, D.; Udd, J.E.; and Hutchinson, D. "Canada/NB MDA project on mine-shaft rope testing; testing of 7/8 in., 1×90, L.C., H.R., (our ropes #13 & #14)"; CANMET Division Report MRL 91-044, 50 pp; April, 1991.

APPENDIX

Tables 1 and 2

as well as Figures 1 through 5, inclusive

Table 1

In-situ and shop-floor test-results

Subject	In-situ	Shop-floor					
	Rot. AC 1988 05 26 Fig. 1a	Rot. AC 1989 04 03 Fig. 1b	Magnogr. 1989 04 04 Fig. 3	LMA-250 1989 04 04 Fig. 4	Rotescogr. 1989 04 04 Fig. 2a	Rotescogr. 1989 04 10 Fig. 2b	WBK 1989 04 10 Fig. 5
tested rope length	2,450 ft	1,020 ft	1,021 ft	1,019 ft	1,060 ft	1,000 ft	1,048 ft
Max. %LMA: @ ft*	4.7%‡ 1,050 – 1,350 ft‡	1.5% 25 ft	2.0% 81 – 138 ft	1.6% 90 – 140 ft	0.9% 125 ft	0.9% 125 – 155 ft	1.0% 21 – 200 ft
0.0% LMA @:	mid-point††	M5	M1	M1	M1	both ends	both ends
calib. @: cage;	yes	yes	yes	yes	yes	—	—
ctwt;	—	—	—	—	—	yes	yes
%LMA diff. betw. ends:	0.0%	1.4%	0.2%	0.3%	0.4%	0.0%	0.0%
%LMA chart-read & (spike-height) @:							
M_1†	—	1.4%;(0.4%)	0.2%;(?)	0.0%;(1.8%)	0.2%;(0.8%)	0.2%;(0.6%)	0.0%;(4.4%)
M_2	—	0.8%;(0.4%)	0.6%;(0.5%)•	0.8%;(1.0%)	0.6%;(0.6%)	0.3%;(0.8%)	—
M_3	—	0.6%;(0.6%)	0.2%;(0.5%)	0.4%;(1.0%)	0.2%;(0.6%)	—	—
M_4	—	0.2%;(0.6%)	0.4%;(0.5%)	0.4%;(1.2%)	0.3%;(0.8%)	0.6%;(0.7%)	0.0%;(4.2%)
M_5	—	0.0%;(0.6%)	0.3%;(0.5%)	0.4%;(1.3%)	0.4%;(0.8%)	0.0%;(?)	—

‡: as reported, vs authors' chart-reading of 2.5% LMA_{max} at 2,450 ft

††: as reviewed by authors; erroneous operator-choice was not reported

*: from the cage rope-end

†: closest to the cage rope-end

•: all 0.5% Magnograph readings too small for accuracy; but clear LF perturbations

Table 2

Details of EM testing of the $1\frac{3}{16}$ in., 1×136, FLC, H.R.

Item No.	Test Instr.	Test No.	Test date	Test location	Instr. operator*	Test chart: Fig. #
1	Rotesco AC	#SH-371	1988 05 26	in-situ	(4)	1a
2	Rotesco AC	7	1989 04 03	shop-floor	(4)	1b
3	Magnograph	#89-286H	1989 04 04	shop-floor	(2)	3
4	LMA-250	—	1989 04 04	shop-floor	(5)	4
5	Rotescograph	—	1989 04 04	shop-floor	(6)	2a
6	Rotescograph	ME-0005RPN	1989 04 10	shop-floor	(6)	2b
7	WBK	—	1989 04 10	shop-floor	(7)	5

*: (7): instr. designer/maker and service company

(2) service company

(4) and (6): mining company

(5) government organization

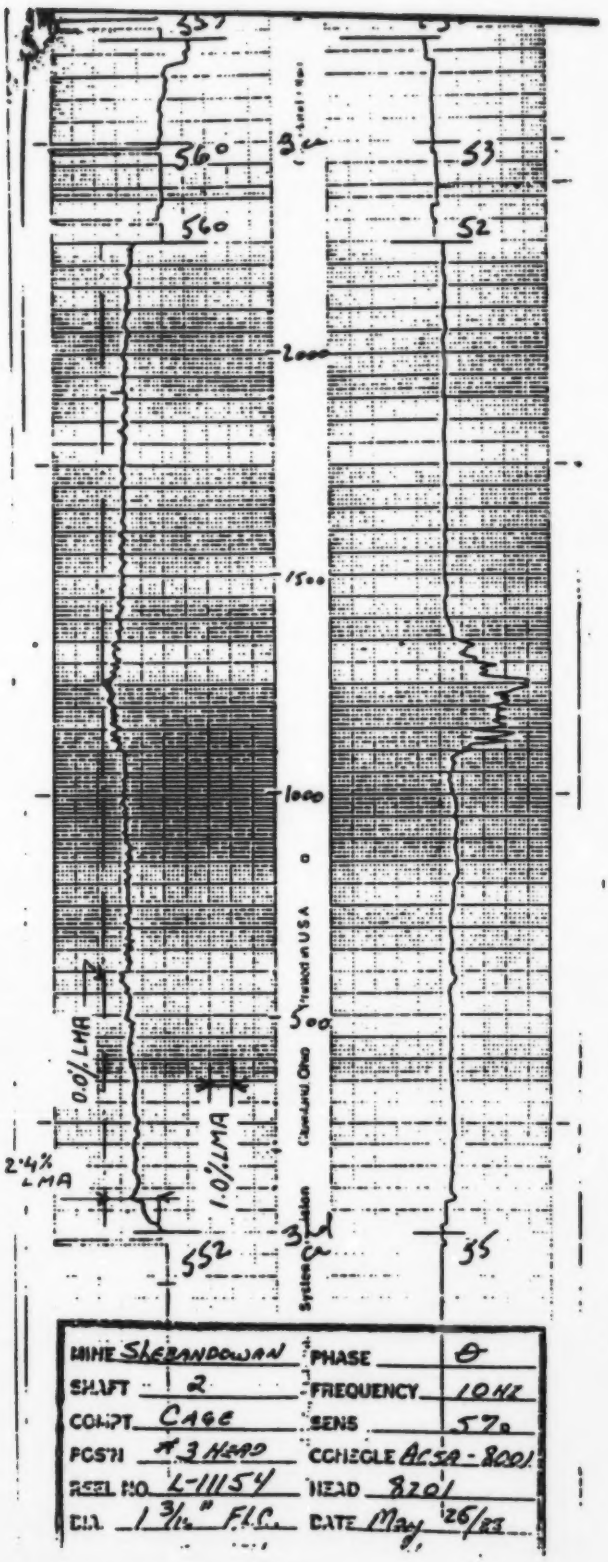


Fig. 1 — Rotesco AC test: (a) in-situ, of 1988 05 26

(b) shop-floor, of 1989 04 03,

as reported

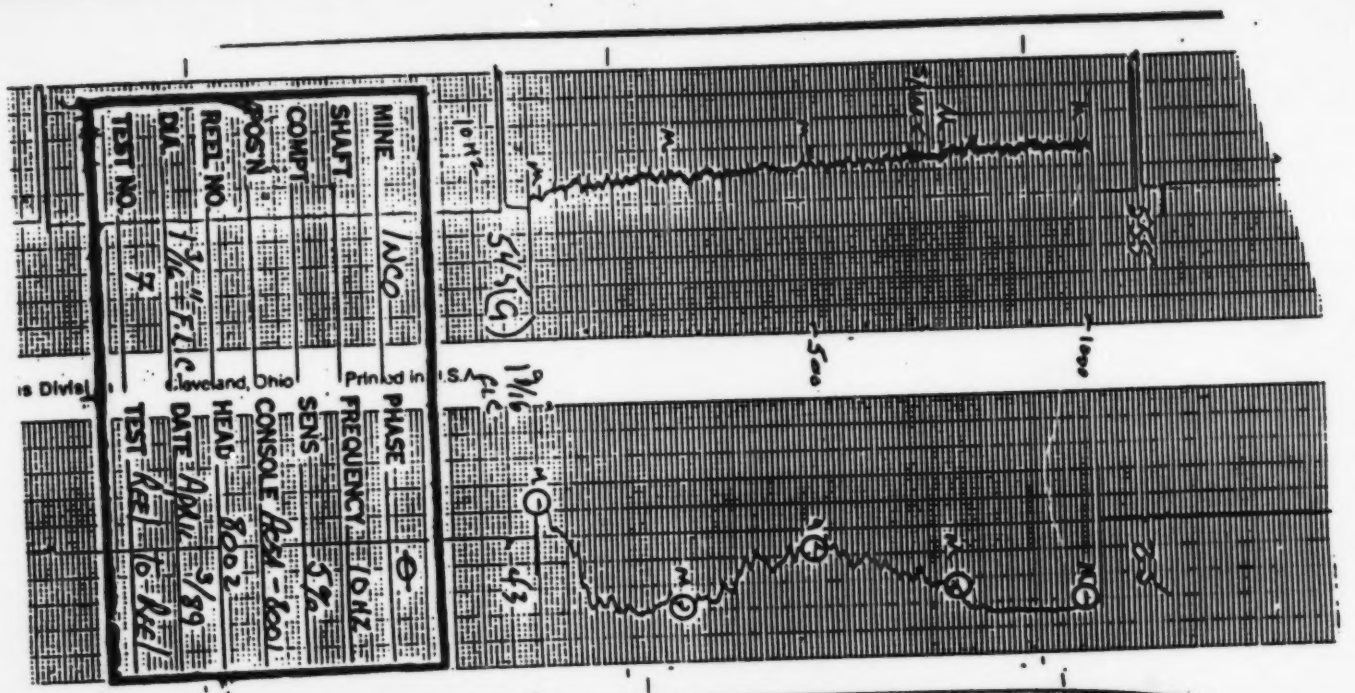


Fig. 1 — Rotesco AC test

(c) shop-floor, of 1989 04 03,

as reviewed

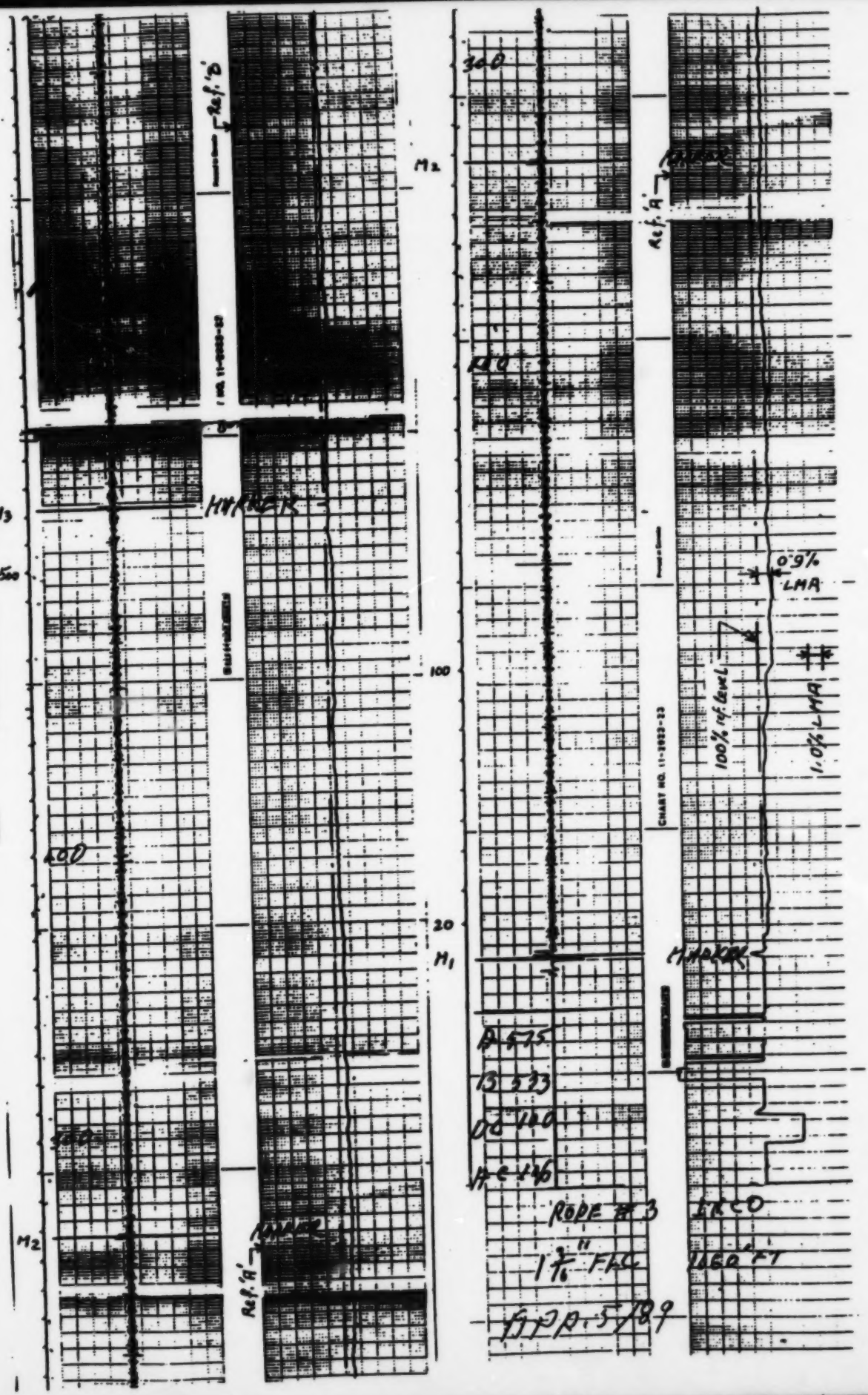


Fig. 2a — Rotescograph test, shop-floor, of 1989 04 04

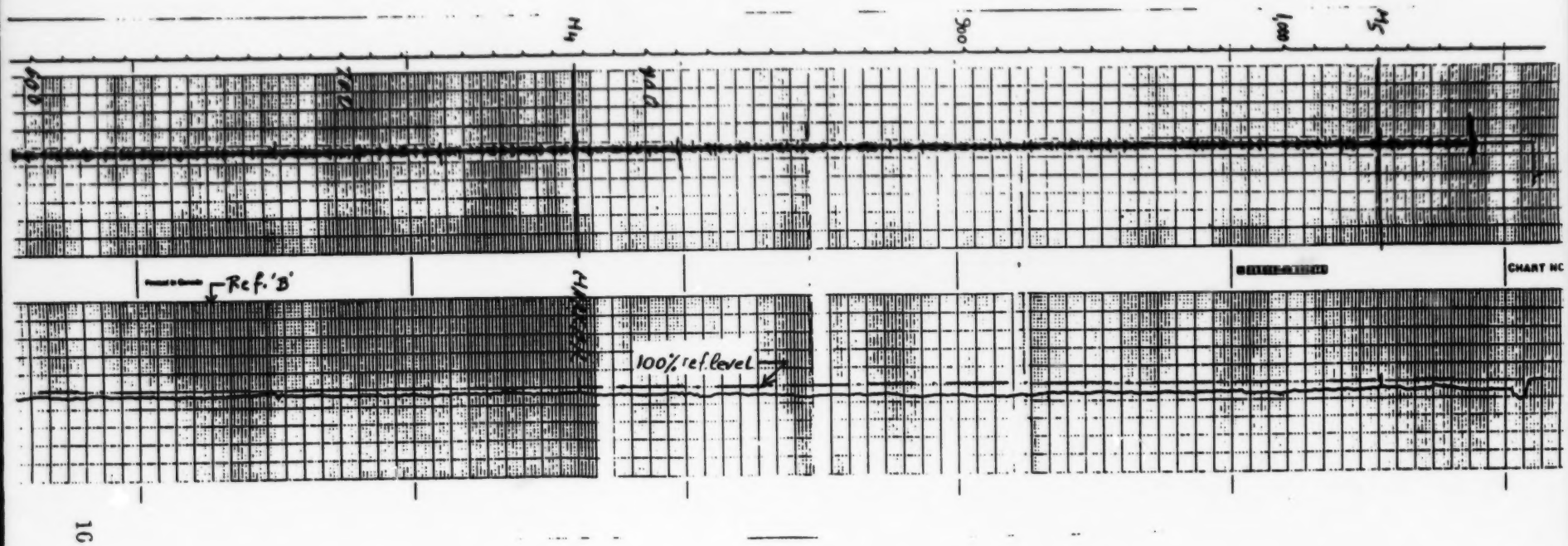


Fig. 2a (continued) — Rotescograph test, shop-floor, of 1989 04 04

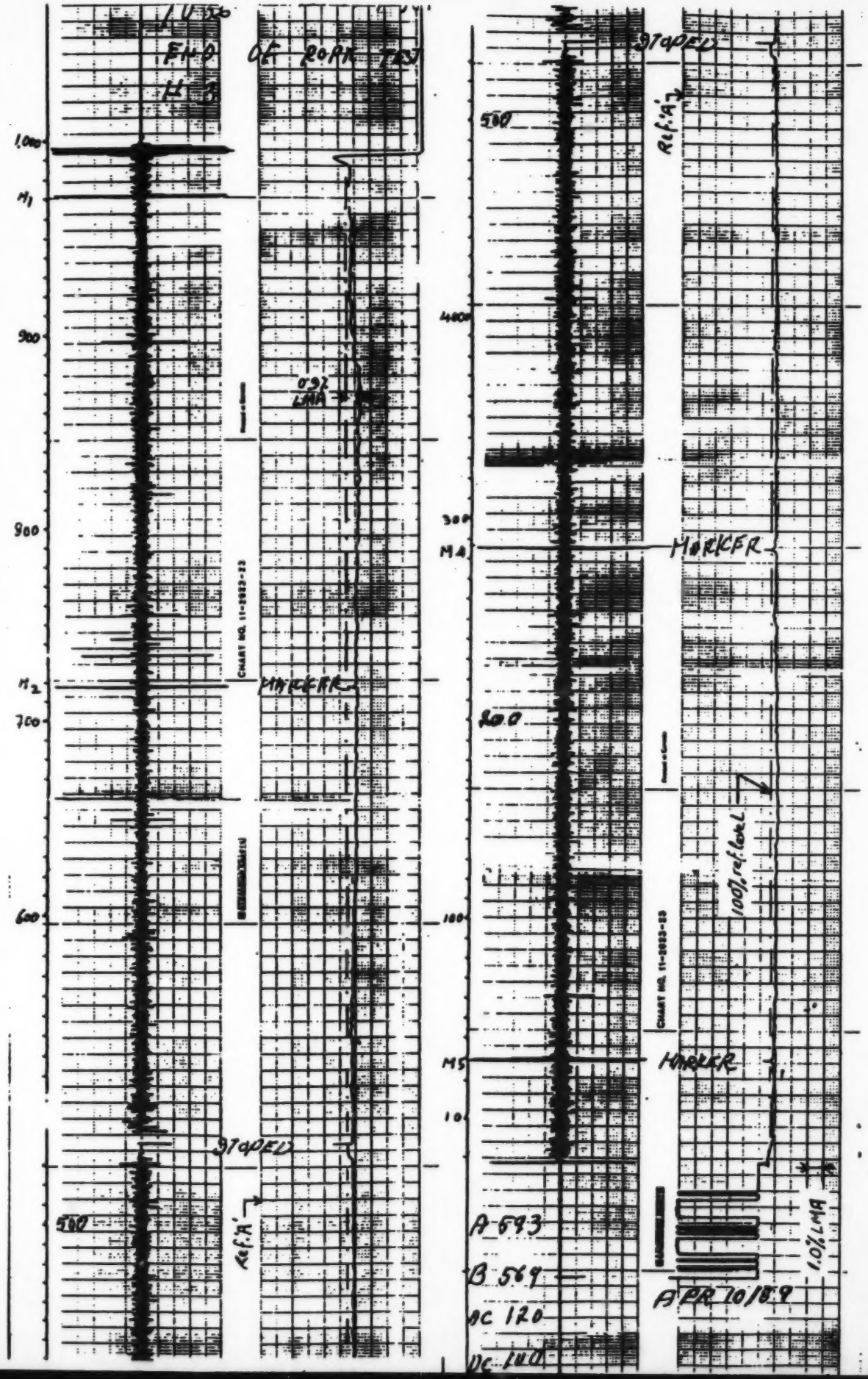


Fig. 2b — Rotescograph test, shop-floor, of 1989 04 10

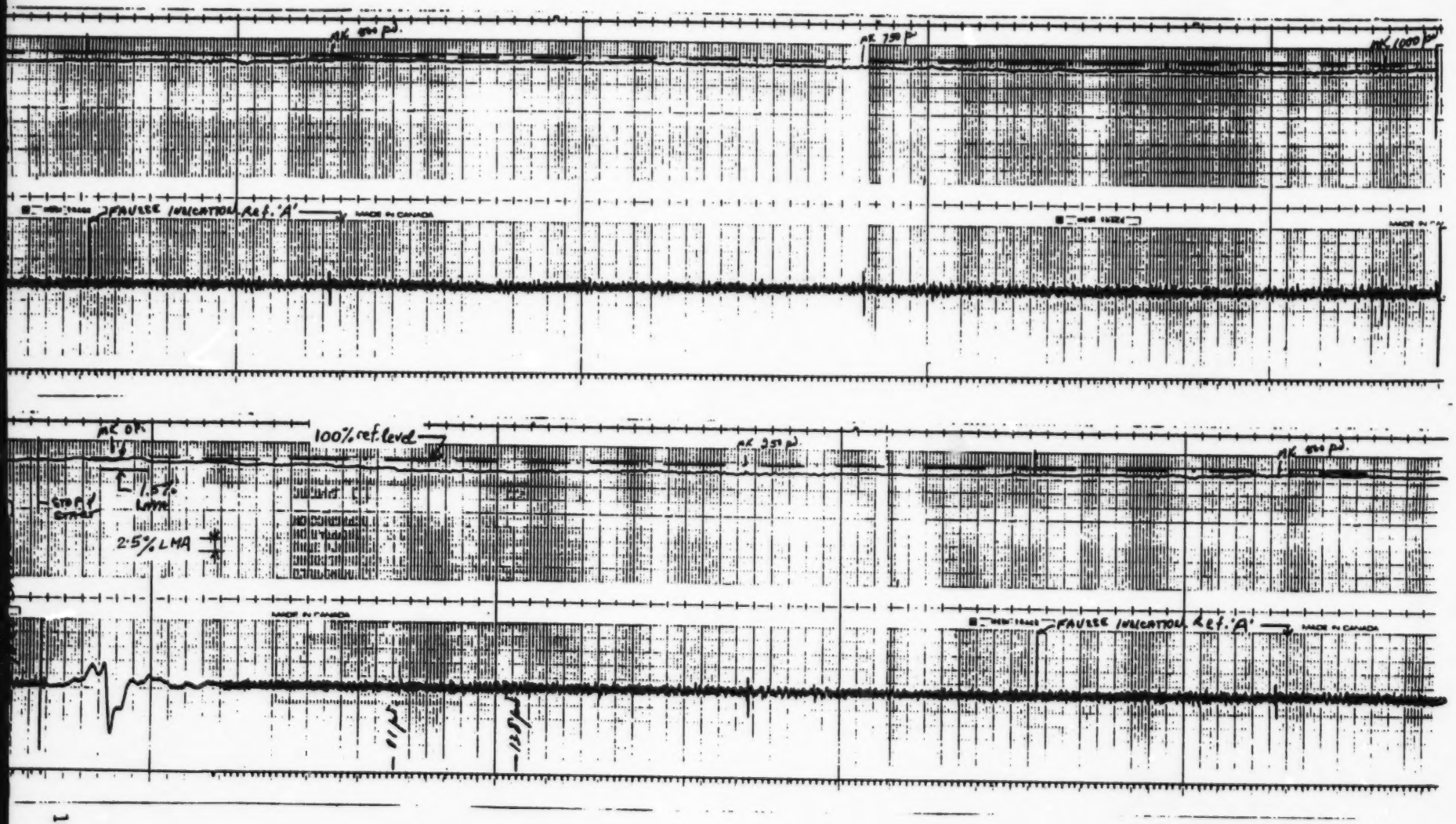


Fig. 3 — Magnograph test, shop-floor, of 1989 04 04

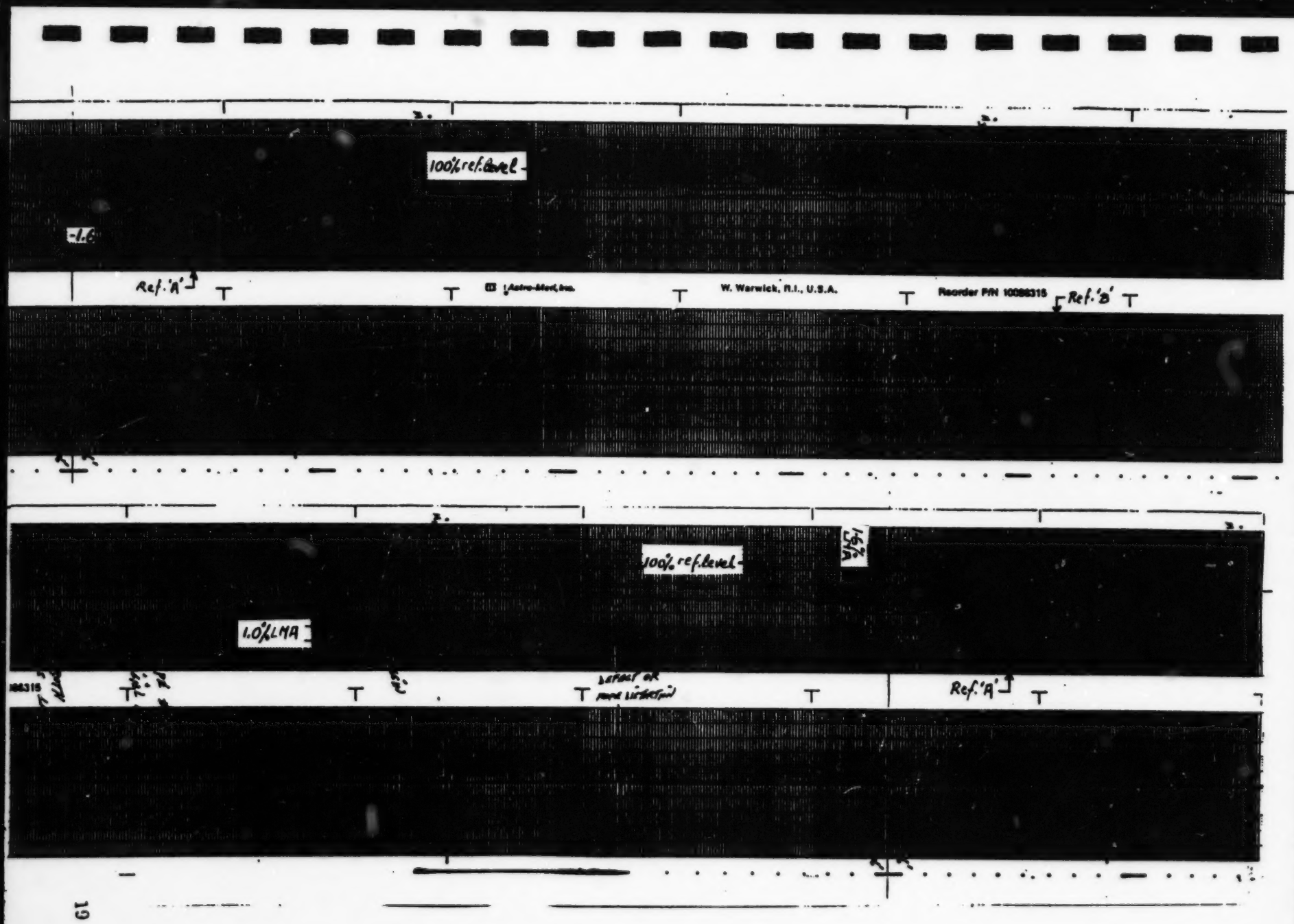
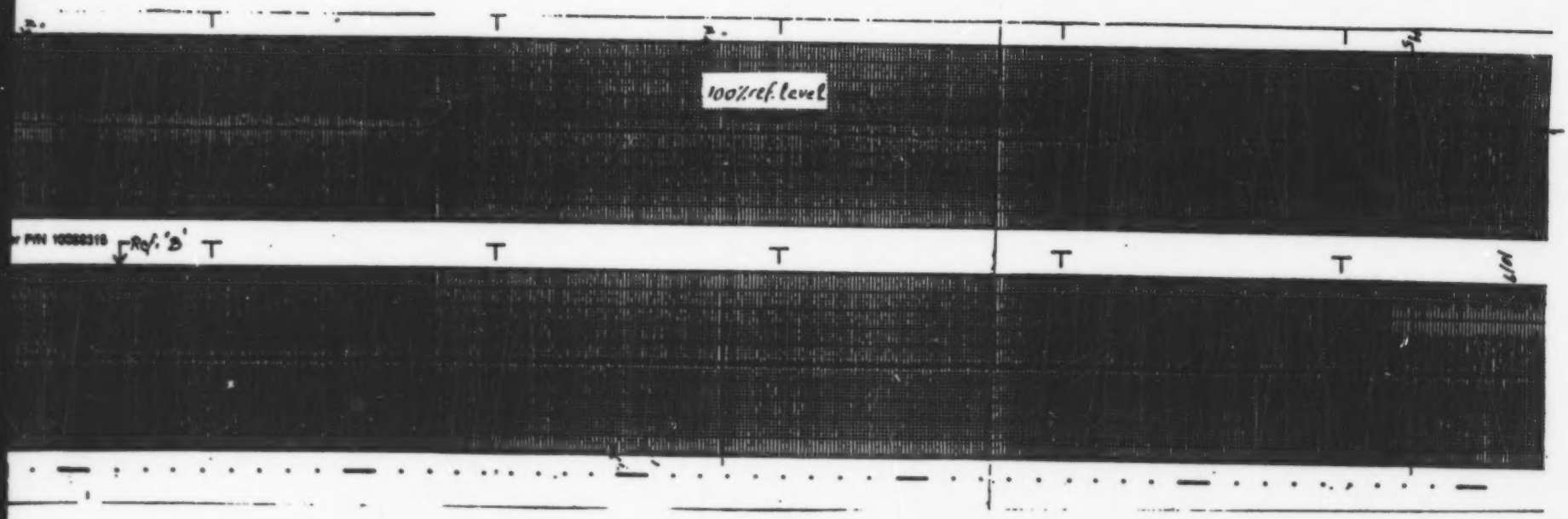


Fig. 4 — LMA-250 test, shop-floor, of 1989 04 04



20

Fig. 4 (continued) — LMA-250 test, shop-floor, of 1989 04 04

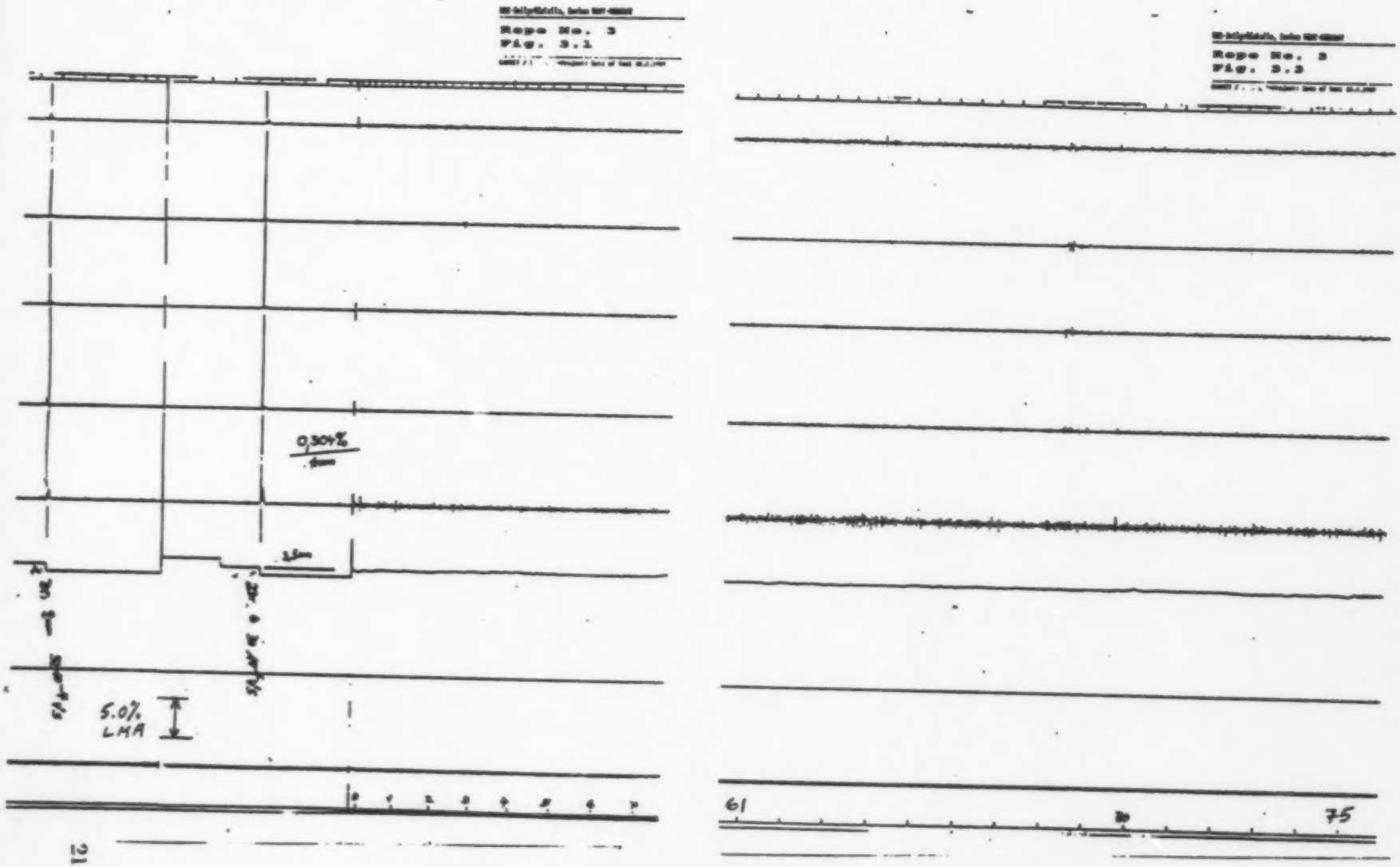


Fig. 5 — WBK test, shop-floor, of 1989 04 10

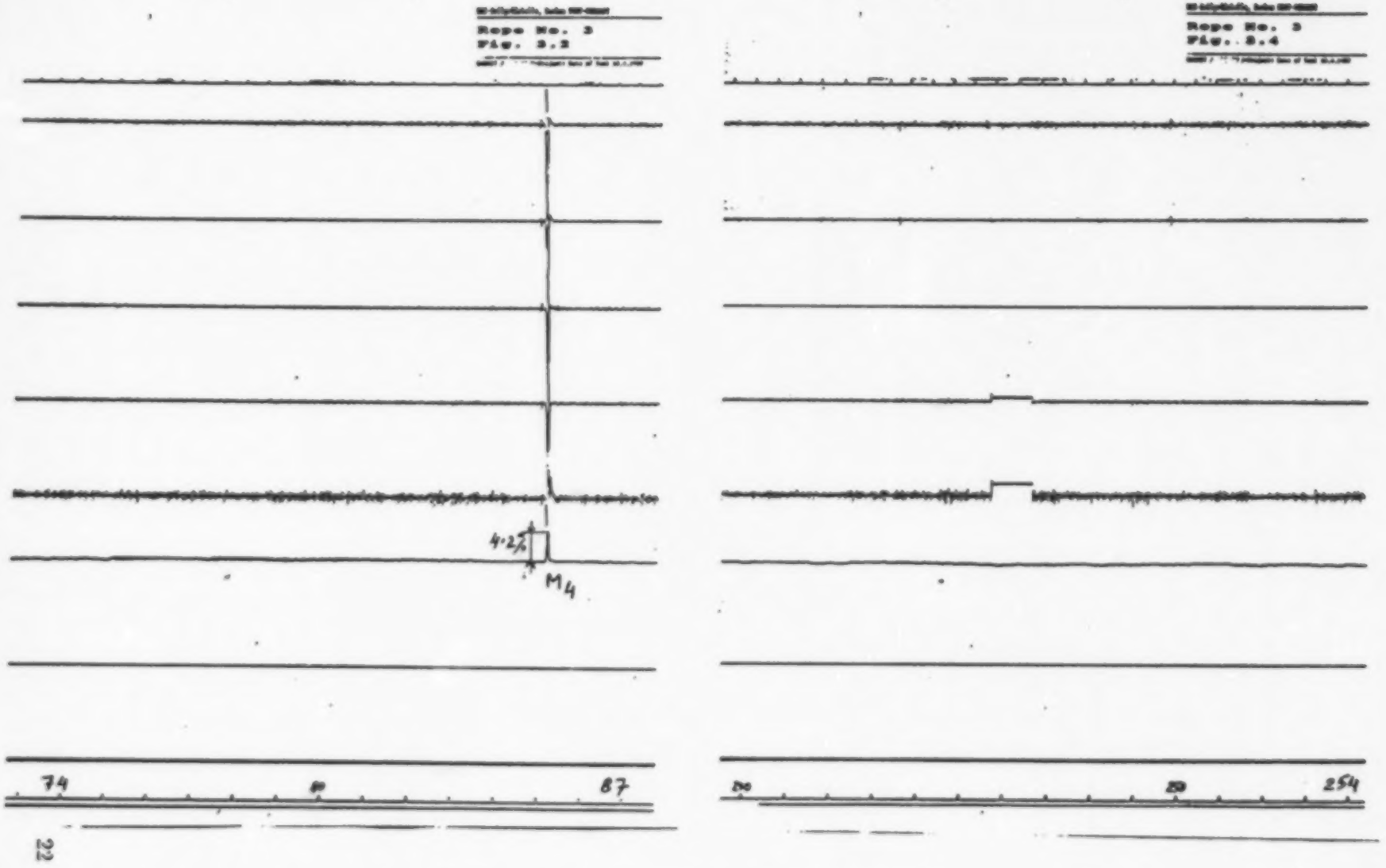


Fig. 5 (continued) — WBK test, shop-floor, of 1989 04 10

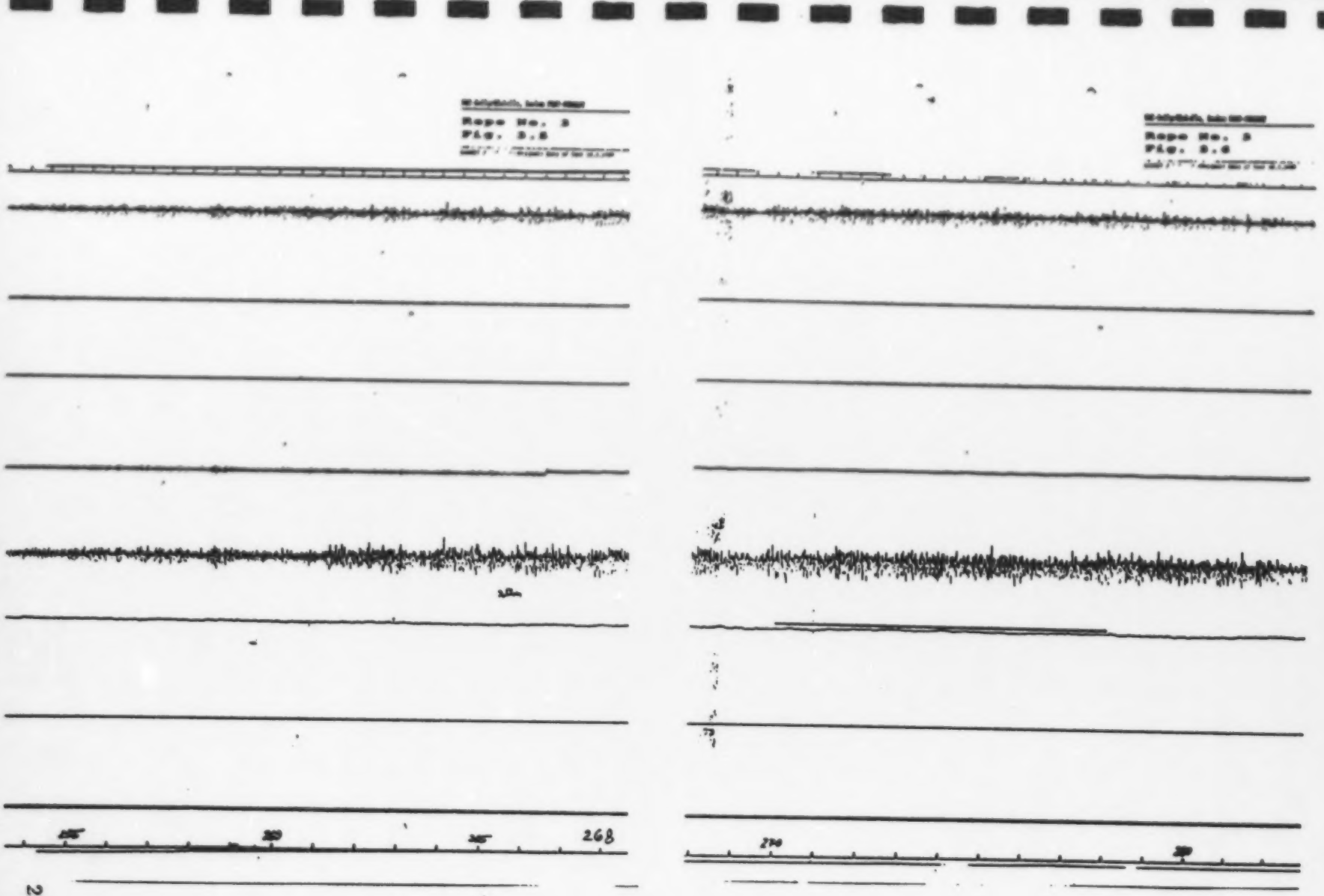


Fig. 5 (continued) — WBK test, shop-floor, of 1989 04 10

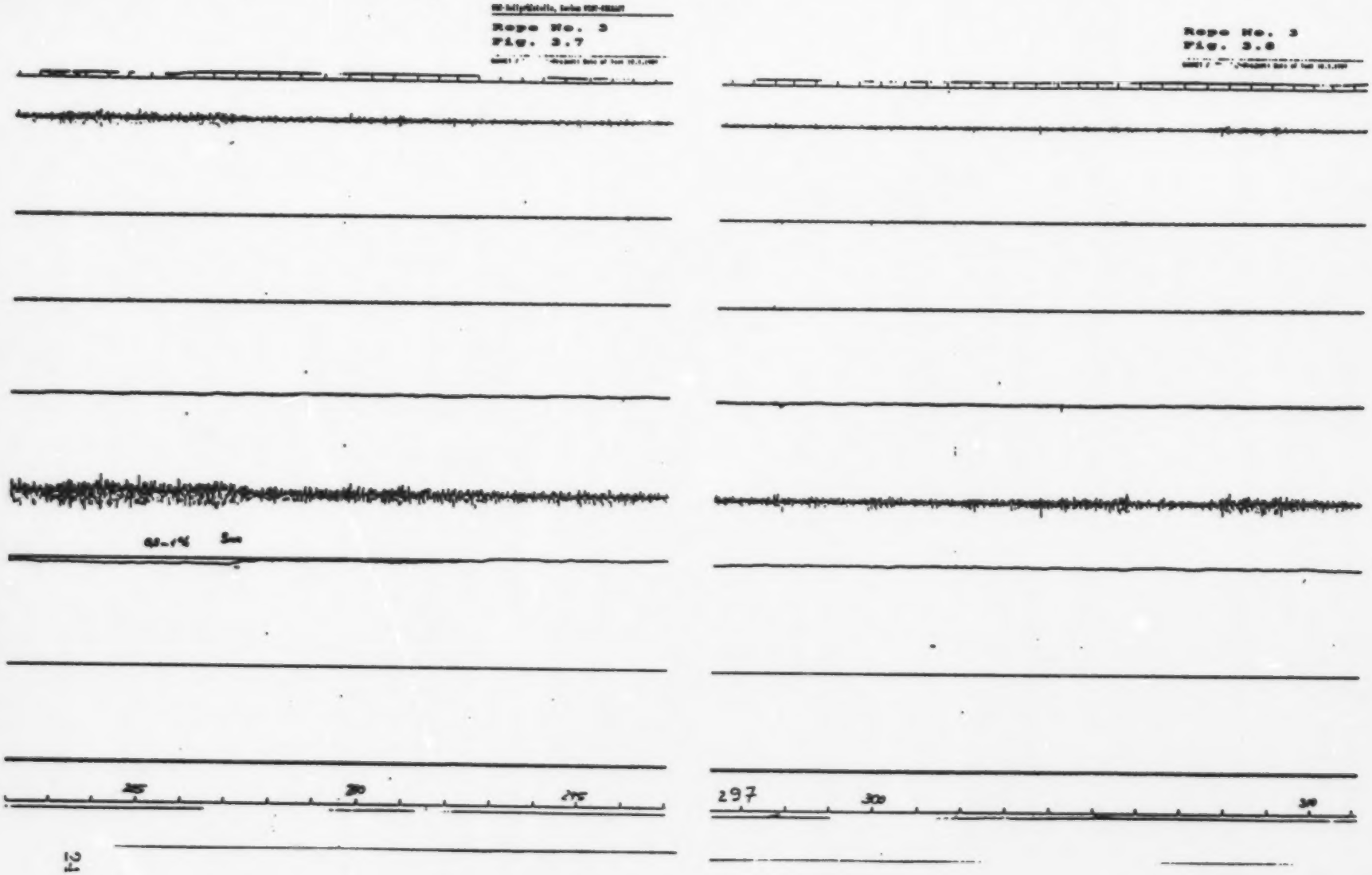


Fig. 5 (continued) — WBK test, shop-floor, of 1989 04 10

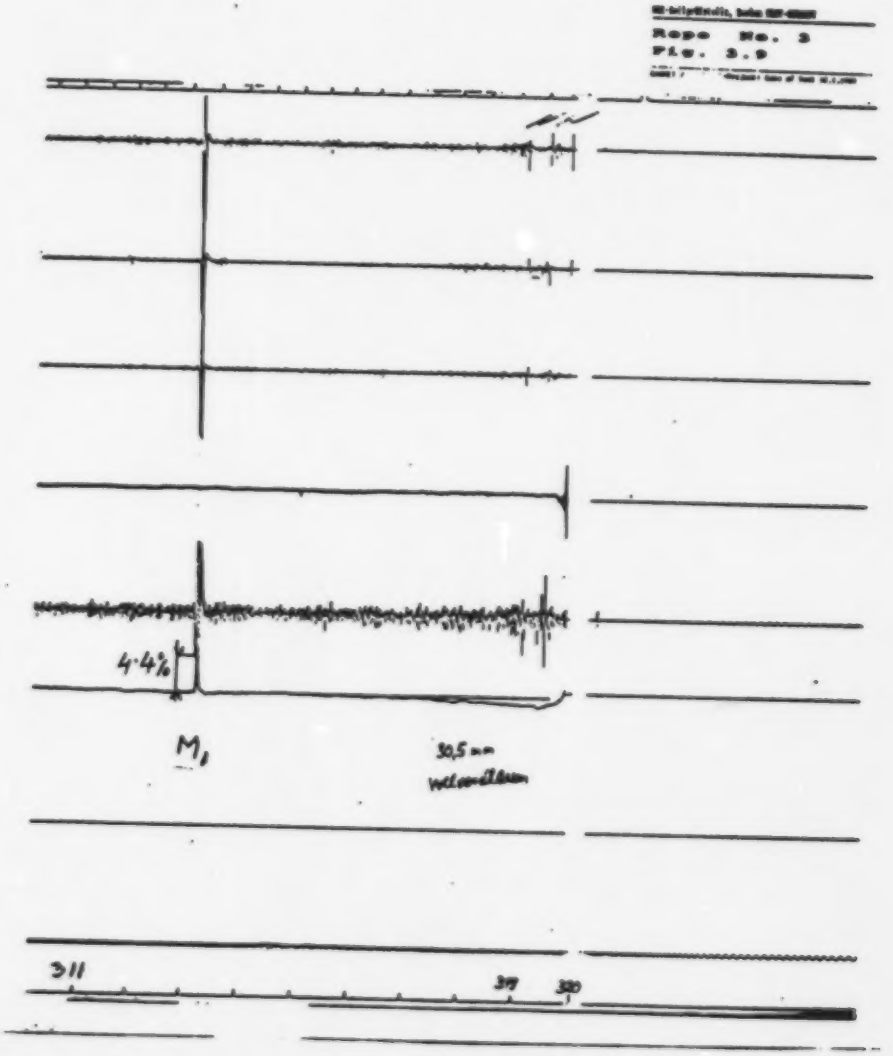


Fig. 5 (continued) — WBK test, shop-floor, of 1989 04 10